SCH 3U – Grade 11 Academic Chemistry

<table>
<tr><td colspan="2">UNIT & TITLE OF LESSON: Quantities in Chemical Reactions – <u>The Limiting Reactant</u></td></tr>
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<u>BIG IDEAS:</u>
- Relationships in chemical reactions can be described quantitatively.
- The efficiency of chemical reactions can be determined and optimized by applying an understanding of quantitative relationships in such reactions.
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<u>OVERARCHING QUESTION:</u> How are Avogadro's number, the mole, and molar mass related and why is it important that health care professionals ensure accountable calculations of prescription dosages?
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<u>MOE SPECIFIC EXPECTATIONS:</u>
<u>A1.1</u>. Formulate relevant scientific questions about observed relationships
<u>D1.1.</u> Analyse processes in the home, the workplace, and the environmental sector that use chemical quantities and calculations, and assess the importance of quantitative accuracy in industrial chemical processes;
<u>D2.1</u> use appropriate terminology related to quantities in chemical reactions, including, but not limited to: stoichiometry, percentage yield, limiting reagent, mole, and atomic mass.
<u>D2.3.</u> Solve problems related to quantities in chemical reactions by performing calculations involving quantities in moles, number of particles, and atomic mass
<u>D2.5</u> calculate the corresponding mass, or quantity in moles or molecules, for any given reactant or product in a balanced chemical equation as well as for any other reactant or product in the chemical reaction.
<u>D2.6</u> solve problems related to quantities in chemical reactions by performing calculations involving percentage yield and limiting reagents
<u>D3.2.</u> Describe the relationships between Avogadro's number, the mole concept, and the molar mass of any given substance.
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<u>PRIOR KNOWLEDGE:</u>
- Understanding of moles and molar ratios
- Comfortable with writing and balancing chemical equations
- Knowledge of mole conversions
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<u>LEARNING GOALS:</u>
- Students will have a clear understanding of what a limiting reagent is
- Students will understand that the amount of product produced is strongly dependent on the limiting reagent
- If given a problem, students will be able to write a balanced chemical equation; determine the limiting reagent and determine the amount of product that will be formed
- Students will be able to make a connection between limiting reagents and its application to real life scenarios
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<u>ASSESSMENT AND EVALUATION:</u>
Knowledge and Understanding:
- Demonstrate understanding of a limiting reagent; calculations of limiting reagents; mole conversions
- Identifying the limiting reagent in a sample problem
Thinking/Inquiry:
- Identifying relationship between limiting reagent and the amount of product able to be produced
Communication:
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MATERIALS
□ Graham crackers, marshmallows, chocolate
APPENDICES
□ Appendix A.1: What's Limiting You? Student instructions
□ Appendix A.2: What's Limiting You? Teacher's notes
□ Appendix B.1: Student worksheet on limiting reactant: The Limiting Reactant
□ Appendix B.2: Teacher's notes on the limiting reactant
□ Appendix C.1: Homework question
□ Appendix C.2: Homework answer
□ Appendix D: Ticket out of class
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- Using appropriate SI unit to work through a problem - Communicating the answers from the calculations to the class through step-by-step explanations *Application:* - Linking the concept of limiting reagents to real-life examples - Connecting the calculations learnt to a medical example	

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TIMING	TEACHING/LEARNING STRATEGY	RESOURCES/NOTES	RATIONALE
Before: Minds On (12min)	**1. Smores Activity to Introduce Limiting Reactants** In groups of 4, have students build as many smores as they can with ingredients provided. One smore consists of 2 crackers, 1 marshmallow, and 2 chocolate pieces. Students answer questions on handout.	Graham crackers, marshmallows, chocolate, *What's Limiting You?* handout **See Appendices A**	Everyone loves food (approach to target different learning styles) AFL – ensure students understand the concept of a limiting ingredient
During: Action (45 min)	**3. Connecting Smores Activity to Limiting Reactant (20 min)** Transition from using smores to chemical equations. Distribute *Limiting Reactant Worksheet* handout and demonstrate one or two examples on the board, involving students in each step. **4. Pair/Share Activity to Complete Worksheet (25 min)** In pairs, students complete remainder of questions on worksheet. Teacher guides students as needed.	*Limiting Reactant Worksheet* handout Blackboard notes **See Appendices B**	Students use existing knowledge of mole conversions to determine limiting reactant and predict amount of product. AFL – ensure students can apply prior knowledge to new concept. AAL – providing descriptive feedback to partner, responding to teacher descriptive feedback
Consolidate (18 min)	**1. Students take up one question on blackboard (10 min)** Teacher asks students to write the answer to one question on the blackboard. Students should describe each step to the class as they go. **2. Antacid as an Example of a Real Life Limiting Reactant (5 min)** Teacher explains the purpose and composition of an Alka-Seltzer. Students will determine which ingredient in an Alka-Seltzer is the limiting reactant. **3. Ticket out of class (3 min)**	Homework question **See Appendices C** **See Appendix D**	AAL – students explaining to class; AOL – students demonstrate to teacher their understanding of concept of limiting reactant and how it is used to calculate amount of product STSE connection keeps students engaged and makes science relevant in life. AAL –students reflection on the day's lesson

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Appendix A.1: Student Handout: ***What's Limiting You?***
Name:

What's Limiting You?

Scenario:

We are surrounded around a campfire, have our sticks and are all set to start roasting some marshmallows to make Smores. A Smore consists of graham crackers, marshmallows and chocolate. The exact components of one Smore is:

- one marshmallow
- two pieces of chocolate
- two graham crackers

Instructions:

1. Arrange yourself into groups of 4.
2. At the centre of the table, gather all the materials to make smores.
3. Using ONLY the materials provided on the table, make as many smores as you can. Remember that 1 smore = 2 crackers + 2 chocolates + 1 marshmallow
4. When you can no longer make any smores, count how many you were able to make using the materials that were provided to you.

Questions:

1. How many smores were you able to make?

2. What limited you from making more smores?

3. What ingredients were in excess?

What's Limiting You?

Materials:

- class of 28 students
- 7 groups of 4
- each group gets:
  - 4 marshmallows (need 4 to make 4 smores)
  - 10 chocolates (would need 8 to make 4 smores)
  - 12 crackers (would need 8 to make 4 smores)
- each group will make 4 smores because there is not enough to make 5 or 6

Scenario:

We are surrounded around a campfire, have our sticks and are all set to start roasting some marshmallows to make Smores. A Smore consists of graham crackers, marshmallows and chocolate. The exact components of one Smore is:

- one marshmallow
- two pieces of chocolate
- two graham crackers

Instructions:

5. Arrange yourself into groups of 4.
6. At the centre of the table, gather all the materials to make smores.
7. Using ONLY the materials provided on the table, make as many smores as you can. Remember that 1 smore = 2 crackers + 2 chocolates + 1 marshmallow
8. When you can no longer make any smores, count how many you were able to make using the materials that were provided to you.

Questions:

4. How many smores were you able to make?
   4

5. What limited you from making more smores?
   Marshmallows

6. What ingredients were in excess?
   Chocolate and crackers

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Appendix B.1 Student worksheet

Name:

The Limiting Reactant

The limiting reactant

What is the relationship between a limiting reactant and a product in a chemical reaction?

Excess reactant

In partners, use your knowledge of mole conversions and mass relationships to answer the following questions. You can follow the steps below to solve stoichiometric calculations.

Write a balanced chemical equation → Identify the limiting reactant. Express it as an amount in moles. → Calculate the amount of the required substance based on the amount of the limiting reactant. → Convert the amount of the required substance to mass or number of particles, as directed by the question.

Questions

1) Lithium nitride reacts with water to form ammonia and lithium hydroxide, according to the following balanced chemical equation:

$$Li_3N_{(s)} + 3H_2O_{(l)} \rightarrow NH_{3(g)} + 3LiOH_{(aq)}$$

If 4.87 g of lithium nitride reacts with 5.80 g of water, find the limiting reactant.

2) 3.76 g of zinc reacts with 8.93×10^{23} molecules of hydrogen chloride. Which reactant is present in excess?

3) White phosphorus consists of a molecule made up of four phosphorus atoms. It burns in pure oxygen to produce tetraphosphorus decaoxide.

$$P_{4(s)} + 5O_{2(g)} \rightarrow P_4O_{10(s)}$$

A 1.00 g piece of phosphorus is burned in a flask filled with 2.60×10^{23} molecules of oxygen gas. What mass of tetraphosphorus decaoxide is produced?

4) Chloride dioxide, ClO_2 is a reactive oxidizing agent. It is used to purify water.

$$6ClO_{2(g)} + 3H_2O_{(l)} \rightarrow 5HClO_{3(aq)} + HCl_{(aq)}$$

a) If 71.00 g of ClO_2 is mixed with 19.00 g of water, what is the limiting reactant?

b) What mass of $HClO_3$ is expected in part (a)?

Appendix B.2 Teacher's notes: *The Limiting Reactant*

Name:

The Limiting Reactant

In the smores activity, the limiting reactant was the marshmallow. In most chemical reactions, there is also a limiting reactant.

The **limiting reactant** is the reactant that is completely used up in a chemical reaction. When the limiting reactant is used up, the reaction stops.

Question: From the smores activity, what is the relationship between the limiting reactant and a product in a chemical reaction?
Expected answer: The amount of product formed depends on the amount of limiting reactant available.

Similar to the smores activity where you had an excess of crackers and chocolate left over…
A reactant that remains after a reaction is over is called the **excess reactant**.

In partners, use your knowledge of mole conversions and mass relationships to answer the following questions. You can follow the steps below to solve stoichiometric calculations.

Write a balanced chemical equation → Identify the limiting reactant. Express it as an amount in moles. → Calculate the amount of the required substance based on the amount of the limiting reactant. → Convert the amount of the required substance to mass or number of particles, as directed by the question.

Questions

Guide students through each step using above process, but also asking them to recall which equations to use.

1) Lithium nitride reacts with water to form ammonia and lithium hydroxide, according to the following balanced chemical equation:

$$Li_3N_{(s)} + 3H_2O_{(l)} \rightarrow NH_{3(g)} + 3LiOH_{(aq)}$$

If 4.87 g of lithium nitride reacts with 5.80 g of water, find the limiting reactant.

- convert mass to moles for Li_3N

$$n \text{ mol } Li_3N = \frac{4.87 \text{ g } Li_3N}{34.83 \text{ g/mol}}$$
$$= 0.140 \text{ mol } Li_3N$$

- pick any product to calculate (NH_3 – since 1 mole is produced) based on amount of Li_3N

$$n \text{ mol } NH_3 = \frac{1 \text{ mol } NH_3}{1 \text{ mol } Li_3N}(0.140 \text{ mol } Li_3N)$$
$$= 0.140 \text{ mol } NH_3$$

- convert mass to moles for H_2O

n mol H_2O = $\frac{5.80 \text{ g } H_2O}{18.015 \text{ g/mol}}$

= 0.322 mol H_2O

- calculate amount of NH_3 made, based on amount of H_2O

n mol = $\frac{1 \text{ mol } NH_3}{3 \text{ mol } H_2O}$ (0.322 mol H_2O)

= 0.107 mol NH_3

Therefore, the limiting reactant is water because the water produces less NH_3 compared with Li_3N. Notice there is more water than lithium nitride, in terms of mass and moles. But because 3 mol of water are needed to react with 1 mol of lithium nitride, water is the limiting reactant.

2) 3.76 g of zinc reacts with 8.93 x 10^{23} molecules of hydrogen chloride. Which reactant is present in excess?

- write a balanced chemical equation

$$Zn_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$$

-convert mass to moles for Zn

n mol Zn = $\frac{3.76 \text{ g Zn}}{65.409 \text{ g/mol}}$

= 0.057 mol Zn

- calculate amount of H_2 made, based on amount of Zn

n mol H_2 = $\frac{1 \text{ mol } H_2}{1 \text{ mol Zn}}$ (0.057 mol Zn)

= 0.057 mol H_2

- convert molecules to moles

n mol HCl = $\frac{8.93 \times 10^{23} \text{ molecules}}{6.02 \times 10^{23} \text{ molecules/mol}}$

= 1.483 mol HCl

- calculate amount of H_2 made, based on amount of HCl

n mol H_2 = $\frac{1 \text{ mol } H_2}{2 \text{ mol HCl}}$ (1.483 mol HCl)

= 0.742 mol H_2

Therefore, Zn is the limiting reactant because it produces less H_2 compared with HCl. Zn is completely used up in the reaction, so HCl is thus the excess reactant that remains after the reaction stops.

Students to complete last 2 questions with partner.

3) White phosphorus consists of a molecule made up of four phosphorus atoms. It burns in pure oxygen to produce tetraphosphorus decaoxide.

$$P_{4(s)} + 5O_{2(g)} \rightarrow P_4O_{10(s)}$$

A 1.00 g piece of phosphorus is burned in a flask filled with 2.60 x 10^{23} molecules of oxygen gas. What mass of tetraphosphorus decaoxide is produced?

- convert mass to moles for P_4

n mol P_4 = $\frac{1.00 \text{ g } P_4}{123.893 \text{ g/mol}}$

= 0.00807 mol P_4

- calculate amount of P_4O_{10} is made, based on amount of P_4

$$n \text{ mol } P_4O_{10} = \frac{1 \text{ mol } P_4O_{10}}{1 \text{ mol } P_4} (0.00807 \text{ mol } P_4)$$
$$= 0.00807 \text{ mol } P_4O_{10}$$

- convert molecules to moles for O_2

$$n \text{ mol } O_2 = \frac{2.60 \times 10^{23} \text{ molecules } O_2}{6.02 \times 10^{23} \text{ molecules/mol}}$$
$$= 0.432 \text{ mol } O_2$$

- calculate amount of P_4O_{10} made, based on amount of O_2

$$n \text{ mol } P_4O_{10} = \frac{1 \text{ mol } P_4O_{10}}{5 \text{ mol } O_2} (0.432 \text{ mol } O_2)$$
$$= 0.0864 \text{ mol } P_4O_{10}$$

Therefore, the limiting reactant is P_4.

- convert mass to moles for P_4O_{10}, using amount calculated from P_4

$$g\ P_4O_{10} = 0.00807 \text{ mol } P_4O_{10} \times 283.886 \text{ g/mol}$$
$$= 2.29 \text{ g } P_4O_{10}$$

Therefore, the amount of P_4O_{10} is 2.29 g.

4) Chloride dioxide, ClO_2 is a reactive oxidizing agent. It is used to purify water.

$$6ClO_{2(g)} + 3H_2O_{(l)} \rightarrow 5HClO_{3(aq)} + HCl_{(aq)}$$

a) If 71.00 g of ClO_2 is mixed with 19.00 g of water, what is the limiting reactant?

- convert mass to moles for ClO_2

$$n \text{ mol } ClO_2 = \frac{71.00 \text{ g } ClO_2}{67.451 \text{ g/mol}}$$
$$= 1.053 \text{ mol } ClO_2$$

- calculate amount of $HClO_3$ formed, based on amount of ClO_2

$$n \text{ mol } HClO_3 = \frac{5 \text{ mol } HClO_3}{6 \text{ mol } ClO_2} (1.053 \text{ mol } ClO_2)$$
$$= 0.8775 \text{ mol } HClO_3$$

-convert mass to moles for H_2O

$$n \text{ mol } H_2O = \frac{19.00 \text{ g } H_2O}{18.015 \text{ g/mol}}$$
$$= 1.055 \text{ mol } H_2O$$

- calculate amount of $HClO_3$ formed, based on amount of H_2O

$$n \text{ mol } HClO_3 = \frac{5 \text{ mol } HClO_3}{3 \text{ mol } H_2O} (1.055 \text{ mol } H_2O)$$
$$= 1.758 \text{ mol } HClO_3$$

Therefore, the limiting reactant is ClO_2 because it produces less amount of $HClO_3$ compared with H_2O.

b) What mass of $HClO_3$ is expected in part (a)?

- convert moles of $HClO_3$, made by the limiting reactant ClO_2, to mass

$$g\ HClO_3 = 0.8775 \text{ mol } HClO_3 \times 84.458 \text{ g/mol}$$
$$= 74.1 \text{ g } HClO_3$$

Therefore, the mass of $HClO_3$ produced is 74.1 g.

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Appendix C.1 Student worksheet

Name:

Limiting Reactants in Everyday Life

Have you ever experienced the effects of excess stomach acid (or acid indigestion)?

Did you take an antacid, such as Alka-Seltzer, for relief?

Alka-Seltzer functions by **neutralizing** excess stomach acid. The fizz you observe when the tablets are placed in water is due to carbonation (dissolving carbon dioxide in water).

The main ingredients in an Alka-Seltzer tablet are **citric acid** and **sodium bicarbonate**. These two ingredients react when placed in water, and form the following chemical equation:

$$C_6H_8O_{7(aq)} + 3NaHCO_{3(aq)} \rightarrow 3H_2O_{(l)} + 3CO_{2(g)} + Na_3C_6H_5O_{7(aq)}$$

In an experiment, 1.00 g of citric acid and 1.92 g of sodium bicarbonate are allowed to react.

a) Which ingredient is the limiting reactant?
b) How many grams of carbon dioxide form?
c) How many grams of excess reactant remain after the limiting reactant is completely consumed?
d) What is the purpose/function of this excess reactant? (think neutralization reaction)

Limiting Reactants in Everyday Life

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The main ingredients in an Alka-Seltzer tablet are **citric acid** and **sodium bicarbonate**. These two ingredients react when placed in water, and form the following chemical equation:

$$C_6H_8O_{7(aq)} + 3NaHCO_{3(aq)} \rightarrow 3H_2O_{(l)} + 3CO_{2(g)} + Na_3C_6H_5O_{7(aq)}$$

citric acid + baking soda → water + carbon dioxide + sodium citrate

In an experiment, 1.00 g of citric acid and 1.92 g of sodium bicarbonate are allowed to react.

a) Which ingredient is the limiting reactant?

- convert mass to moles for citric acid

$n \text{ mol } C_6H_8O_7 = \frac{1.00 \text{ g } C_6H_8O_7}{192.123 \text{ g/mol}}$

$= 5.20 \times 10^{-3} \text{ mol } C_6H_8O_7$

- calculate amount of H_2O formed, based on amount of $C_6H_8O_7$

$n \text{ mol } H_2O = \frac{3 \text{ mol } H_2O}{1 \text{ mol } C_6H_8O_7} (5.20 \times 10^{-3} \text{ mol } C_6H_8O_7)$

$= 0.0156 \text{ mol } H_2O$

- convert mass to moles for baking soda

$n \text{ mol } NaHCO_3 = \frac{1.92 \text{ g } NaHCO_3}{84.015 \text{ g/mol}}$

$= 0.0229 \text{ mol } NaHCO_3$

- calculate amount of H_2O formed, based on amount of $NaHCO_3$

$n \text{ mol } H_2O = \frac{3 \text{ mol } H_2O}{3 \text{ mol } NaHCO_3} (0.0229 \text{ mol } NaHCO_3)$

$= 0.0229 \text{ mol } H_2O$

Therefore, the limiting reactant is the citric acid.

b) How many grams of carbon dioxide form?

- calculate amount of CO_2 formed, based on amount of citric acid

$n \text{ mol } CO_2 = \frac{3 \text{ mol } CO_2}{1 \text{ mol } C_6H_8O_7} (5.20 \times 10^{-3} \text{ mol } C_6H_8O_7)$

$= 0.0156 \text{ mol } CO_2$

- convert moles to mass

$g \; CO_2 = 0.0156 \text{ mol } CO_2 \times 44.009 \text{ g/mol } CO_2$

$= 0.687 \text{ g } CO_2$

Therefore, 0.687 g of carbon dioxide is formed.

c) How many grams of excess reactant remain after the limiting reactant is completely consumed?

- find how much sodium bicarbonate is consumed in reaction by using the moles of the limiting reactant

$$n \text{ mol } NaHCO_3 = \frac{3 \text{ mol } NaHCO_3}{1 \text{ mol } C_6H_8O_7} (5.20 \times 10^{-3} \text{ mol } C_6H_8O_7)$$
$$= 0.0156 \text{ mol } NaHCO_3$$

Therefore, 0.0156 mol of $NaHCO_3$ is consumed during the reaction with citric acid.

- convert moles to grams

$$g\ NaHCO_3 = 0.0156 \text{ mol } NaHCO_3 \times 84.015 \text{ g/mol}$$
$$= 1.31 \text{ g } NaHCO_3$$

Therefore, 1.31 g of $NaHCO_3$ is consumed during the reaction.

- to find how much remains, subtract initial amount by the consumed amount

$$g\ NaHCO_3 = 1.92 \text{ g} - 1.31 \text{ g}$$
$$= 0.61 \text{ g } NaHCO_3$$

Therefore, 0.61 g of $NaHCO_3$ remains after the reaction is complete.

d) What is the purpose/function of this excess reactant? (think neutralization reaction)

Sodium bicarbonate helps to decrease acidity in the stomach (HCl) in a neutralization reaction to neutralize excess stomach acids, producing water and carbon dioxide.

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Appendix D: ***Ticket out of class***

Exit Ticket: Rate how comfortable you feel solving problems involving limiting reagents.

Rating Scale:

1	**2**	**3**	**4**	**5**
Not very comfortable				Very comfortable